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We present and test a conceptual and methodological approach for interdisciplinary sustainability assessments of water governance systems based on what we call the sustainability wheel. The approach combines transparent identification of sustainability principles, their regional contextualization through sub-principles (indicators), and the scoring of these indicators through deliberative dialogue within an interdisciplinary team of researchers, taking into account their various qualitative and quantitative research results. The approach was applied to a sustainability assessment of a complex water governance system in the Swiss Alps. We conclude that the applied approach is advantageous for structuring complex and heterogeneous knowledge, gaining a holistic and comprehensive perspective on water sustainability, and communicating this perspective to stakeholders.

Keywords: water governance; water management; sustainability; interdisciplinary assessment; indicators; visions

1. Introduction

In Switzerland, as in many other parts of the world, there is increasing concern that water shortage problems might become more frequent. Consequently, many research and policy efforts focus on issues of more sustainable water governance. However, there are few holistic approaches, which evaluate the sustainability of water governance systems based on comprehensive, interdisciplinary assessments (Reed and Kasprzyk 2009; Wiek and Larson 2012). Most frameworks emphasize singular aspects such as quality and supply of freshwater resources (Kondratyev *et al.* 2002), infrastructure, adaptive capacity (Hill 2013), or social learning (Pahl-Wostl 2006; Pahl-Wostl *et al.* 2007). Moreover, studies that investigate the sustainability of water governance systems from holistic perspectives (Larson, Wiek, and Withycombe Keeler 2013) primarily focus on the present situation without in-depth assessments of possible future developments.

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A holistic framework for the analysis of sustainable water governance systems is proposed by Wiek and Larson (2012). Their framework combines a systemic understanding of the water governance system and its evaluation through a set of sustainability principles. They stress the importance of justifying the normative claims in the system analysis with a transparent set of value laden sustainability principles.

Another approach that is commonly chosen to evaluate water governance sustainability from an interdisciplinary perspective is the application of indicators (Sullivan and Meigh 2007; Valenzuela Montes and Matarán Ruiz 2008; Ioris, Hunter, and Walker 2008; Babel *et al.* 2011; Lachavanne and Juge 2009). The great advantage of indicators is that they provide a reasonably simple tool to combine biophysical and socioeconomic information (Sullivan and Meigh 2007), and allow the reflection and communication of complex ideas by condensing their multifaceted nature into a manageable amount of meaningful information (Babel *et al.* 2011), yielding good learning opportunities (Ioris, Hunter, and Walker 2008). However, they also have limitations; quantitative indicators often require (over)simplifying complex and dynamic water governance systems (Ioris, Hunter, and Walker 2008). Consequently, aspects that are hard to measure, or hard to quantify, such as informal governance practices, are neglected (e.g. Lachavanne and Juge 2009). Furthermore, gaps in data often limit the applicability and information value for different case study areas.

Against this background, our goal is to present a conceptual and methodological approach for an interdisciplinary sustainability assessment for water governance systems – based on what we call the sustainability wheel – and its application in the Crans-Montana-Sierre region of Switzerland, the case study area of the MontanAqua project (Weingartner *et al.* 2010). For this purpose, we took the basic ideas of the two approaches described above and combined them in a way that would allow the evaluation of the water governance system through a comprehensive, interdisciplinary assessment.

In this article, we use the term water governance system in a broad sense. Water governance systems are understood to include social practices and institutions, as well as biophysical aspects and processes. When using the term water resource systems, we only refer to the biophysical aspects and processes.

2. The case study area

The case study area Crans-Montana-Sierre region (Figure 1) is located on a southern slope in the canton Valais and covers an area of 130 km^2. It contains considerable variation in elevation (from 500 masl in the Rhône river valley bottom to 3000 masl on the Plaine Morte Glacier) and a strong hydrological gradient; the difference between precipitation and evapotranspiration averages about 150 mm/y in Sierre and more than 2200 mm/y at high elevations. It is one of the driest areas of Switzerland (Weingartner and Spreafico 2010). The region encompasses 11 communes (6 communes on the Haut-Plateau and 5 on the slope or the Valley bottom) and 4 main watersheds, and is drained by several small streams flowing towards the Rhône River. The discharge of meltwater from the Plaine Morte Glacier is an important water resource for the region.

The organization of the study area in terms of land and water use is characterized by a stratified altitudinal structure (Reynard 2001): a regional center (Sierre, with a population of 15,000) in the Rhône River valley bottom; several villages with residential and agricultural (viticulture, livestock) activities in the lower parts of the mountainside; and the tourist resort of Crans-Montana (skiing, golf, hiking) at more than 1500 masl. With more than 37,000 tourist beds, Crans-Montana is one of the largest mountain tourist

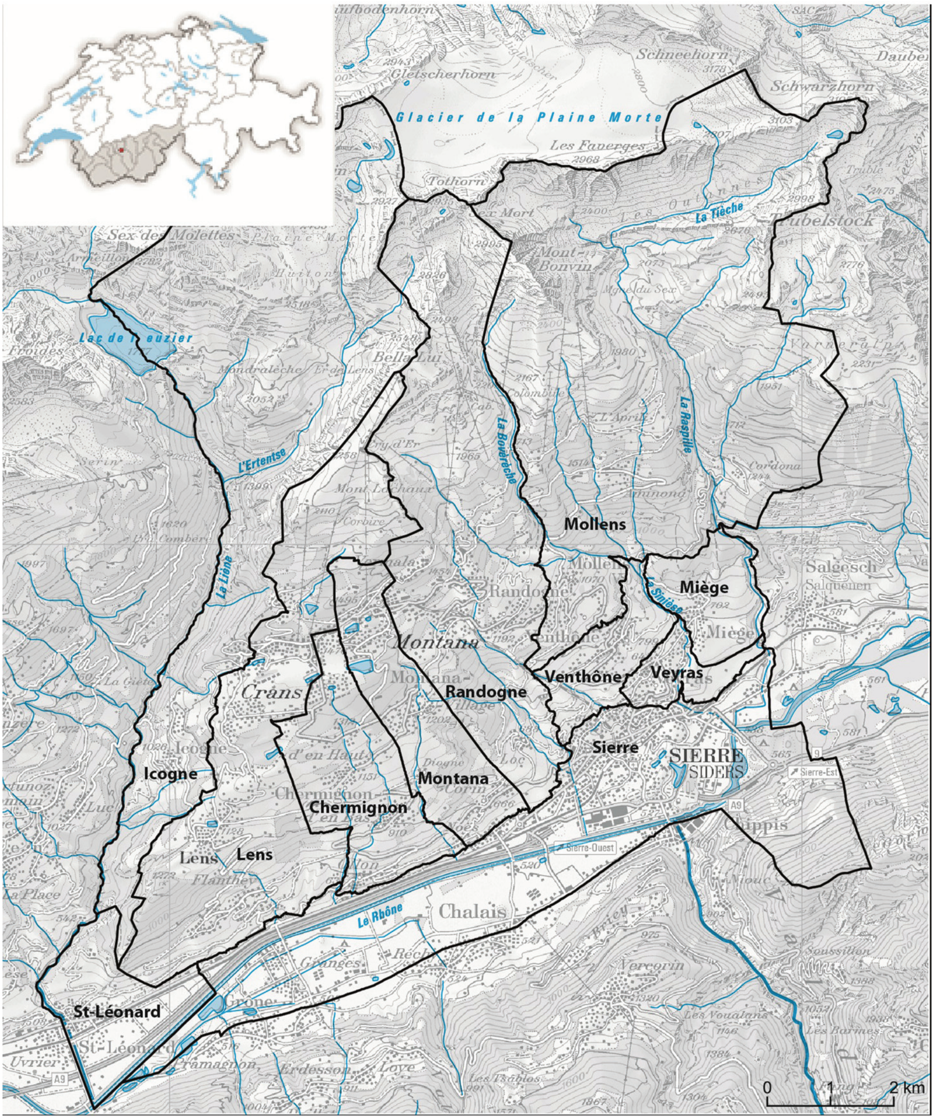

Figure 1. The 11 communes of the Crans-Montana-Sierre region (Schneider and Homewood 2013).

resorts in Switzerland. Moreover, the largest amount of water by far is used for hydropower production and stored in an artificial reservoir (Tseuzier Lake).

In the past, the region has faced a diverse set of water scarcity problems, which emerged from the dynamic socioeconomic developments, the multiplicity of different water uses (drinking water, irrigation, artificial snow production, hydropower, etc.), and the highly unequal distribution of water resources (Reynard 2000b, 2000a; Schneider and Homewood 2013).

The boundaries of the water governance system investigated in this study were delineated taking into account the interactions between the biophysical units, such as river catchments, as well as the sociopolitical units of decision making, water transfer, and water use (Wiek and Larson 2012). More specifically, while the 11 communes manage their water independently – only in recent years have they started to create intercommunal cooperations – they all depend on water from the same mountain areas above them.

3. Conceptual and methodological approach

Our conceptual and methodological approach follows four main steps:

(1) Interdisciplinary analysis of the water governance system
(2) Development of sustainability principles
(3) Contextualization and indicator development
(4) Assessment of the sustainability of the water governance system: the sustainability wheel

3.1. Interdisciplinary analysis of the water governance system

A systemic understanding that relates hydrological, ecological, social, economic, technical, legal, and cultural aspects is the fundamental basis of a sustainability appraisal (Reed and Kasprzyk 2009; Wiek and Larson 2012). This appraisal must encompass reflections on the boundaries of the water governance system (see Section 2), the areas of focus, and the systemic cause–effect structure (Wiek and Larson 2012). This, in turn, requires developing and synthesizing empirical knowledge originating from different scientific disciplines.

Consequently, our research focuses on four interrelated areas, taking into consideration present and future (2050) conditions:

- Water availability: How much water is available?
- Water use: How much water is used?
- Decision making: How are decisions made over water distribution and use?
- Stakeholders' perspectives: What meaning do stakeholders give to water?

Research on the status of the current system was based on hydrometeorological and land use measurements and modeling (for more details see Huss, Voinesco, and Hoelzle 2013; Finger *et al.* 2013), as well as participatory observation, qualitative interviews, and analysis of existing reports and statistical data (see Bonriposi 2013; Reynard and Bonriposi 2012; Schneider and Homewood 2013). Research on possible future situations was based on visioning techniques, modeling, and calculations (Reynard *et al.* 2014). In a participatory process with local stakeholders (group RegiEau), we developed four future visions that encompass stakeholders' different priorities of how their region should develop (regional development, infrastructure, and institutional reforms); the fourth vision (Vision RegiEau) represents a consensus of the participating stakeholders. Important aspects of the four visions are displayed in Table 1 (for more details see Schneider and Rist 2013a). These visions were then translated to water use scenarios as a basis for simulating future water demands (see Bonriposi 2013). For modeling future water use, as well as resource availability, we used International Panel on Climate Change (IPCC) A1B climate change scenarios (CH2011 2011) (see also Huss, Voinesco, and Hoelzle 2013; Reynard *et al.* 2014).

Table 1. Overview on the four future visions (adapted from Schneider and Rist 2013a).

Topics	Vision1: growth strategy	Vision 2: stabilization strategy	Vision 3: moderation strategy	Vision of the RegiEau group
Overall strategy	Growth is at the heart of the region's development. Mass tourism, lucrative activities, and second homes are the main focus. Water resources and landscape are important, but not top priorities. Indeed, the inhabitants of Crans-Montana-Sierre feel that there is enough water for the future, thanks to engineering measures (supply management)	Water and landscape are among the region's most important resources. They are indispensable both for tourism and for the local population's wellbeing. For this reason, regional development in Crans-Montana-Sierre follows alternative approaches aimed at more efficient resource use. Water management focuses in particular on optimising water consumption (demand management)	Development in the Crans-Montana-Sierre region is oriented primarily towards improving the quality of life for residents and visitors. Creating jobs is just as important as maintaining an adequate drinking water supply and conserving a healthy cultural landscape. Water and landscape use are in line with the needs of the local economy	Consensus based on stakeholders' discussions of the other three visions. It represents a mixture of Visions 2 and 3
Regional development				
Demography	Strong population growth	Slight population growth	Population decrease	Slight population growth
Water consumption	No water saving efforts	Water supply has become more efficient	Water supply has become more efficient	Water supply has become more efficient
	Drinking water is at times used for irrigation	Separate drinking water and irrigation water networks	Separate drinking water and irrigation water networks Great efforts to save water	Separate drinking water and irrigation water networks, including in residential areas
Spatial planning	Unrestrained building activities (under current legislation)	Densification Construction of second homes is restricted Construction of small apartment buildings is encouraged	Building industry has developed into reconstruction and energy efficient renovation industry Some previous building areas have been rezoned as non-developable areas	Densification Construction of second homes is restricted Construction of small apartment buildings is encouraged

(*continued*)

Table 1. (*Continued*)

Topics	Vision1: growth strategy	Vision 2: stabilization strategy	Vision 3: moderation strategy	Vision of the RegiEau group
Tourism	Mass tourism based mainly on skiing and golf (new snow cannons and golf greens)	Tourism has become more attractive all year round Skiing area has been reduced	Tourism industry focuses on "soft" tourism based on gastronomic and outdoor activities linked with a broad range of cultural and educational offers	Tourism has become more attractive all year round Skiing area has been reduced
Agriculture	Agriculture is not a priority Farming has become increasingly extensive	Agriculture plays important role in food production (especially meat)	Agriculture is highly important to the region and primarily serves tourism, nature conservation, and landscape maintenance	Agriculture is highly important to the region and serves tourism, nature conservation, and landscape maintenance
Viticulture	Viticulture has been intensified (increased profitability) Sprinkler irrigation	Viticulture is continued at same level of intensity (high quality wine) Drip irrigation	Viticulture has become increasingly extensive (high quality wine, biodiversity) Drip irrigation	Viticulture is continued at same level of intensity (high quality wine) Drip irrigation
Hydropower	Hydropower production is of utmost importance The hydropower potential of all rivers is fully tapped	Hydropower production has high priority, but other water needs are considered equally important (irrigation, drinking water, etc.)	Hydropower production is important, but the goal is to reduce energy consumption and diversify energy sources	Hydropower production is important, but the goal is to reduce energy consumption and diversify energy sources
Infrastructure development				
Pipelines	New storage, transport and pumping infrastructures are built.	Interlinked drinking water network, separation of drinking water and irrigation water, perfect maintenance	Interlinked drinking water network, separation of drinking water and irrigation water, perfect maintenance	Interlinked drinking water network, separation of drinking water and irrigation water, perfect maintenance New storage, transport and pumping infrastructures are built

(*continued*)

Table 1. (*Continued*)

Topics	Vision1: growth strategy	Vision 2: stabilization strategy	Vision 3: moderation strategy	Vision of the RegiEau group
Storage capacities	New storage lake (Tièche)	No additional storage capacities	Dispersed storage of rain water by households	Dispersed storage of rain water
Institutional reforms				
Collaboration	No new forms of collaboration; Putting one's own needs first	Centralized water management, however, decision making power stays with the communes	United water management for the wellbeing of all inhabitants of the region	United water management for the wellbeing of all inhabitants of the region
Water rights	No water rights reform	Water rights reform	Water rights reform (from private to public rights)	No waters right reform
Residual water	No water withdrawals when discharge less than 25l/s	No water withdrawals when discharge less than 50l/s	No water withdrawals when discharge less than 100l/s	No water withdrawals when discharge less than 50l/s

3.2. Development of sustainability principles

While many studies and reports on water governance refer to the concept of sustainability, few of them systematically reflect on the value base of sustainability and about what it means to contextualize the general principles of sustainability in specific contexts (Schneider and Rist 2013b). Consequently, only few authors elaborate transparent and value laden sustainability principles (Wiek and Larson 2012). In-depth reflection on the underlying values of a more sustainable future and its contextualization for specific water governance systems (discussed in the following section), however, is fundamental for defining actions for more sustainable water governance and recasting policy discourse (White 2013).

According to the definition formulated in the Brundtland Report, "… sustainability implies a concern for social equity between generations, a concern that must logically be extended to equity within each generation" (WCED 1987, ch. 2 para 3). This means that sustainable water governance systems should allow the current generation to meet their societal goals in an equitable way without compromising the water options of future generations (ASCE and UNESCO 1998). Based on these general ideas, and taking into account other literature on water sustainability or governance (e.g. Gleick 1998; Wiek and Larson 2012; Pahl-Wostl 2009; Hill 2013; Gibson 2006), we derived four main principles for sustainable water governance systems:

(1) *Contribution to societal goals of regional development*: This first principle states that people living today, and in the future, should be able to meet their development goals. Water availability should allow them to satisfy diverse needs ranging from household consumption and recreation to economic activities such as production of food, energy, or other goods and services.
(2) *Maintenance of ecological and hydrological integrity*: Maintaining the ecological and hydrological integrity of water resource systems is crucial for meeting development goals of not only the current population, but especially of future generations. This second principle is about the quality and quantity of surface and groundwater as well as about the benefits and harms to the ecosystem resulting from diverse water uses (Kondratyev *et al.* 2002).
(3) *Contribution to social justice*: As stated in the Brundtland definition of sustainability (WCED 1987), justice concerns should not only be considered between generations, but also within the current generation. Consequently, social justice has to be regarded as a basic element of water sustainability.
(4) *Adaptive capacity*: In times of increasing uncertainty due to socioeconomic and climate changes, the ability to flexibly respond and adapt to changing supply and demand is an essential requirement for the sustainability of water governance systems (Pahl-Wostl 2009). Adaptive capacity is therefore considered a fourth main principle of a sustainable water governance system (ASCE and UNESCO 1998). It refers to the capacity of actors to create and respond to variability and change, as well as the impacts on the state of the system in both proactive and reactive ways (Hill 2013; Adger, Arnell, and Tompkins 2005)

3.3. Contextualization and indicator development

In order to make the four normative and rather abstract principles for water sustainability operational, they need to be broken down into more concrete sub-principles that spell out what it means to make specific water governance arrangements in specific contexts more sustainable (Schneider and Rist 2013a). In other words, a contextualized understanding of the sustainability principles is needed to achieve a certain fit with the local circumstances (Hartmuth, Huber, and Rink 2008). Consequently, through iterative discussion, the interdisciplinary research team broke down the four main principles into three–five indicators each, taking into account the scientific literature (Sullivan and Meigh 2007; Valenzuela Montes and Matarán Ruiz 2008; Ioris, Hunter, and Walker 2008; Babel *et al.* 2011; Wiek and Larson 2012), the meanings stakeholders give to water, as well as the specific characteristics of the case study region.

Concretization of the first principle – c*ontribution to societal goals of regional development* – was based on a participatory visioning process and a set of stakeholder interviews (Schneider and Rist 2013a). This brought four major dimensions to the forefront: water for basic needs, recreation and enjoyment, agriculture, and hydropower production. For specifying the other three principles, we mainly drew on existing literature and context knowledge within the team of researchers. For the principle of *ecological integrity*, we found that quality and quantity of surface and groundwater resources are among the most widespread indicators (e.g. Sullivan and Meigh 2007; Ioris, Hunter, and Walker 2008; Wiek and Larson 2012). However, ecosystems can also benefit from, or be harmed by, specific water uses such as irrigation of species rich dry meadows or artificial snow production (Rixen, Stoeckli, and Ammann 2003).

For the principle of *justice*, we refer to recent literature (Fraser 2009; Schlosberg 2007) that stipulates that justice assessments should not only focus on just outcomes of resource distribution processes (distributive justice), but also on the fairness of governance processes themselves (procedural justice), as well as on the context, "which incorporates the pre-existing conditions that limit or facilitate people's access to decision making procedures, resources and, thereby, benefits" (contextual justice) (McDermott, Mahanty, and Schreckenberg 2013, 416). For the principle of *adaptive capacity*, the indicators are derived from a study of Schneider and Homewood (2013) that found that the adaptive capacity of the water governance system in the case study region is influenced by the actors' access to financial, material, and social resources including collaborative capacity and entitlements (Olsson *et al.* 2006; Babel *et al.* 2011), as well as effective demand management mechanisms (resource efficiency) and a high learning capacity, which allow anticipating potential problems and developing farsighted solutions (Tompkins and Adger 2004; Folke *et al.* 2005; Olsson *et al.* 2006; Pahl-Wostl *et al.* 2007). See Table 2 for an overview on the indicators we have defined for the study region.

3.4. Assessing the sustainability of the water governance system: the sustainability wheel

After setting the framework, we assessed the defined sustainability indicators, taking into consideration the totality of regional knowledge available through the previous literature and novel research results of the participating researchers. To structure this comprehensive information and increase the ease with which it is communicated to the stakeholders, we designed a sustainability wheel. Its design and structure were inspired by the work of Gupta *et al.* (2010) on adaptive capacity ("the adaptive capacity wheel"). In our case, the inner circle shows the four main principles of sustainable water governance; the outer circle presents the indicators that specify each principle (see Figure 2).

To consider the multifaceted and complex interrelationships characterizing the collected knowledge about the water governance system in place, we did not conduct a quantitative

Table 2. Description of indicators for the four sustainability principles for the Crans-Montana-Sierre region.

Principles	Indicators	Description
Regional development	Basic needs	Water governance should allow the people to meet their basic needs concerning household water uses such as drinking, cooking, and sanitation
	Recreation and enjoyment	Water governance should enable the people to pursue recreation and enjoyment, specifically by benefiting from water in the landscape (historical water channels, lakes, rivers, wetlands, cultural irrigated landscapes, glaciers), and tourism related activities
	Agriculture	Water governance should enable the people to practice agriculture and viticulture to produce local food and forage, and to maintain the cultural landscape
	Hydropower production	Water governance should allow benefit from the region's high potential for hydropower production
Ecological integrity	Groundwater quantity	Aquifers should not be overexploited beyond the long term regeneration and recharge rates
	Surface water quantity	Minimum flows in surface water (rivers, lakes, water channels) should be guaranteed for fish, wildlife, and ecosystems, as well as for recreation and enjoyment
	Water quality	The quality of water resources for ecosystems and humans should be ensured by eliminating, reducing, or mitigating pollution
	Benefits (and harms) of water use	Water uses in the landscape, such as artificial snow production and irrigation, should not harm the ecosystem
Justice	Distributive justice	Benefits, costs, and risks are equitably distributed among all actors involved in water use and governance
	Procedural justice	Decision making processes related to water use and governance are based on normative frameworks (rule of law), disclosure of relevant information (transparency), and principles of impartiality (non-discrimination). There are institutions that facilitate negotiation and collective decision making between all actors concerned
	Contextual justice	Different water user groups and communes have comparable capabilities to access and benefit from water
Adaptive capacity	Material and financial capital	Available financial capital and infrastructure should allow exploiting the available water resource, to flexibly divert it, and to buy water from others
	Collaborative capacity	Actors involved are able to respond to water problems through formal and informal means of coordination and cooperation based on trust, joint visions, and power sharing (e.g. functional water markets, effective cooperation platforms and networks, joint planning)

(*continued*)

Table 2. (*Continued*)

Principles	Indicators	Description
	Institutions and entitlements	Institutions and entitlements (e.g. property rights, concessions, formal, and informal rules) of water governance arrangements provide predictability and certainty, as well as flexibility, in order to respond to water shortage crises
	Resource efficiency	Water demand can be reduced through effective water demand management, including more efficient irrigation techniques, separation of drinking water and irrigation water, repairing leaky infrastructure
	Learning capacity	Actors are involved in continuous learning processes, allowing them to anticipate potential problems and to find adequate answers. There are opportunities for learning by doing, knowledge exchange, transparency of information, monitoring, and assessments, as well as participatory strategy development

assessment, but a qualitative one. Thus, the assessment of the indicators was based on a deliberative dialogue and scoring process within our team of 13 interdisciplinary researchers (hydrologists, sociologists, glaciologists, human and physical geographers, specialists in water and land use, and management). It took place in a two day workshop following the scoring protocol proposed by Gupta *et al.* (2010). In a first step, research results that were relevant for assessing certain indicators were presented. Based on this information, each researcher rated each indicator on a five point scale (very good, good, moderate, poor, very poor). To visualize the results and ease their interpretation, the traffic light color system was applied, where dark red means very poor sustainability, yellow moderate, and dark green very good sustainability. Subsequently, we discussed the ratings in order to find common ground and agree on a single rating per indicator. This procedure was repeated for each indicator for the present as well as for four different future visions. Finally, all indicators were jointly reassessed in order to harmonize the ratings and to get a coherent overall picture. After this, we translated the collected information to a storyline in order to give meaning to the individual indicator scores.

A qualitative assessment of sustainability indicators is at risk for being judged as subjective, since it requires that the researchers interpret and score research results. To address this risk, we organized the scoring process as transparently as possible and required that the scoring was justified by scientific evidence (if this was not possible, the indicator was not rated). Furthermore, a moderator oversaw that the knowledge bases and arguments of the participating researchers were considered equally and that the final scoring was based on an agreement of the best argument.

The resulting sustainability wheels, their scoring, and related storylines are presented in Section 4.

4. The sustainability of the water governance system of Crans-Montana-Sierre

4.1. Sustainability assessment of the present

The sustainability wheel of the present (Figure 3) clearly shows that the present water governance system of Crans-Montana-Sierre region can principally allocate sufficient

Figure 2. The sustainability wheel for the water governance system in Crans-Montana-Sierre.

water to achieve society's goals of regional development (scored as good); however, its performance regarding ecological integrity, adaptive capacity (both scored as moderate), and especially regarding justice (scored as poor) is more limited.

4.1.1. Societal goals of regional development

The good evaluation of this first principle was the product of the good rating of three indicators – *basic needs*, *recreation and enjoyment*, and *hydropower*; only *agriculture* is scored as moderate.

4.1.1.1. Basic needs. Water supply for all the inhabitants and visitors is guaranteed throughout the year (Bonriposi 2013). Nevertheless, we did not score this indicator as very good, as some communes (e.g. Veyras) have very few water resources and are highly dependent on other communes for their water provisioning. Other communes, in particular those in the tourist resort, face water shortages during wintertime and are forced to buy water from neighboring communes. Conventions for water exchanges do

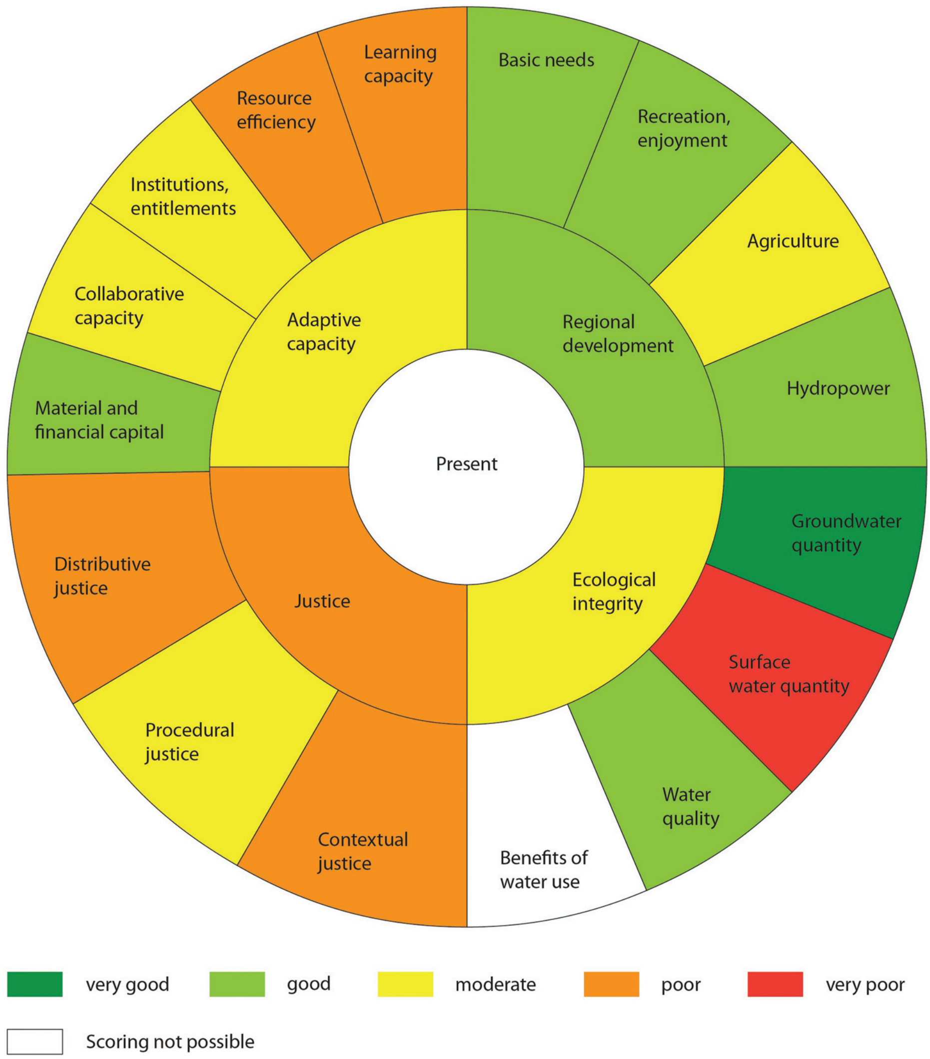

Figure 3. The sustainability wheel for the present for the Crans-Montana-Sierre region. See online color version for full interpretation.

not always exist in writing; therefore, during some periods (winter low discharge months, dry periods in summer) there is always the risk for the dependent communes to face shortages. Moreover, during some dry periods, some communes use the water held in reserve for fighting fire for drinking water distribution (Schneider and Homewood 2013).

4.1.1.2. Recreation and enjoyment. The regional landscape is shaped by many water elements (lakes, rivers, historical water channels, glacier, and irrigated cultural landscapes). Inhabitants and tourists alike can enjoy its beauty and engage in outdoor activities such as boating, swimming, hiking, or skiing (Clivaz and Reynard 2008). Quite a large amount of water is also used for watering gardens and parks (Reynard and Bonriposi 2012). There are some minor constraints, mostly in dry years when the lakefronts become unattractive due to reduced water levels or no water flows in the rivers and water channels.

4.1.1.3. Agriculture. Irrigation is a crucial requirement for farming on the dry slopes. Generally, water availability enables farmers to raise livestock and grow grapes to produce local products (cheese, wine), as well as to maintain cultural rural landscapes. However, grassland production is the economic activity most affected by water shortages. For example, not all fields are equipped for irrigation (e.g. if situated above the water channels), and in dry years (e.g. 2003) rivers and lakes can be depleted and use restrictions applied, especially during the second part of summer. Consequently, the second grass cut may not be irrigated (Kobel 2014). While water rights favor agriculture (historical water rights for irrigation), in reality, during shortage periods agriculture is the most vulnerable and priorities are given to other uses (drinking water and also tourist uses). Viticulture is less affected by water shortages because grapes can generally withstand (not too intense) water shortages (Buff 2012).

4.1.1.4. Hydropower production. Hydroelectricity production depends on abundant precipitation and the meltwater from the glacier and snow. Snowmelt varies significantly from one year to the other, whereas glacier melting is more regular, and is predicted to increase due to climate warming until about 2050 when it will reach its maximum (Huss, Voinesco, and Hoelzle 2013). While hydropower production could be developed even further, in the last 20 years it has been considered to have been fully profitable from an economic point of view (La Lienne SA 2012).

4.1.2. Ecological integrity

The ratings of the various ecological integrity indicators are very diverse. While *groundwater quantity* and *water quality* are rated very good and good, respectively, *surface water quantity* is rated very poor. Due to insufficient knowledge, no rating was possible for the *benefits of water use*.

4.1.2.1. Groundwater quantity. Apart from some very small local marshes and peat bogs, there are no real aquifers on the steep slopes of the study region. Many springs in the region are sustained by karstic underground water circulation (Finger *et al.* 2013), others by slope water, which has its origin in large weathered hillside rocks or old fluvial deposits (Crestin 2001). These springs cannot be overused as they are recharged during snowmelt season (spring and early summer) and after rain events. The same is true for the large aquifers in the bottom of the valley, which are seasonally recharged by infiltration from the Rhône river during its seasonal high waters from March to September (Schürch and Vuataz 2000).

4.1.2.2. Surface water quantity. Even though there are abundant water resources in the study region, in many smaller streams and brooks little water flow is observed (Reynard 2000b). This is due to the fact that in the existing concessions for water withdrawals for hydraulic power production and for irrigation, no residual flow rules were imposed. The Swiss Water Protection Act has regulated residual flow by law since 1991. However, existing residual flow stretches only have to be remediated by law insofar as this is economically acceptable (Swiss Confederation 2013). Ultimately, residual flow will be imposed with the renewal of the hydropower concession of the Liène catchment in 2037.

4.1.2.3. Water quality. Most houses in the region are linked to the sewer system that discharges all wastewater from the study region down to the central waste water plant in Sierre (Bonriposi 2013). The proportion of intense agricultural land use is small; therefore, problems with fertilizers or pesticides are generally negligible. As a result, water quality is not a significant problem in the region. Occasionally, water quality problems can occur because of livestock husbandry. In this karstic region, springs are very vulnerable to such kind of pollution. Eutrophication has been observed in a few ponds (Reynard 2000b, 2000a).

4.1.2.4. Benefits of water use. It was not possible to evaluate this important indicator as there was no sufficient knowledge available for an appraisal of the effects of artificial snow production or irrigation on ecosystems such as dry meadows.

4.1.3. Justice

The justice principle indicator ratings show that water justice as a whole is currently rather poor in the region, whether in terms of resource allocation and costs or at a legislative level.

4.1.3.1. Distributive justice. Costs, risks, and benefits of water are very unequally distributed in the region. For instance, the water richest commune (Icogne), with just a few hundred inhabitants, can use more than 50% of the water resources available (Reynard *et al.* 2014). Not only does this provide relief from any water scarcity problems, but it has also enabled Icogne to grant hydropower concessions and consequently to collect considerable amounts of water interest rates (Schneider, Buser, and Graefe, forthcoming). On the other hand, the water poorest commune (Veyras) has to buy most of its drinking water from other communes and is, therefore, highly dependent on their surplus water. Moreover, water prices can vary more than 100% from one commune to another, and infrastructure costs are also highly variable.

4.1.3.2. Procedural justice. Access to water and the organization of public management bodies is regulated on different levels (national, cantonal, communal, and private laws), and decision making is mostly transparent. There is nevertheless a multitude of bilateral agreements among the different water users that are not easily accessible. At times, there is a lack of transparency because the situation is too complex, e.g. nobody has an overview about the water rights situation, or decisions are based on oral customary law and informal agreements. Most problematic is the aspect of inclusiveness. No institution exists that embraces all relevant water users on a regional level and can mediate the diverse interests of the water users (Schneider and Homewood 2013).

4.1.3.3. Contextual justice. The capabilities of the communes and other water users to access water are very unequal for various reasons. First of all, communes that contain large high mountain catchments including rivers and springs can use much higher amounts of water than communes on the lower slopes that do not possess their own wells. Second, communes that have historically held water rights for sources outside their communes have more opportunity to obtain sufficient water (Reynard 2000b, 2000a). Third, ancient water rights mainly favor agricultural water users and hinder new water users from accessing water (e.g. for tourism and urbanization). Finally, communes with higher negotiating power can secure more favorable agreements with other communes or other user groups. This is the case for the six communes of the Haut-Plateau, which are better coordinated than the communes on the lower slopes.

4.1.4. Adaptive capacity

The appraisal of the adaptive capacity indicators provides very heterogeneous results (Schneider and Homewood 2013). While the adaptive capacity based on *material and financial capital* is rated as good, adaptive capacity based on *collaboration* and *entitlements* are both rated as moderate, and on *resource efficiency* and *social learning* as poor.

4.1.4.1. Material and financial capital. Development of supply and distribution infrastructure represents the main focus of the water governance system. It has made it possible to exploit the available water resource and to transport it from the water rich mountain areas to farming areas and villages on the dry slopes (Quaglia 1988; Ammann 2011; Bréthaut 2012; Reynard 2000b). Moreover, relatively high financial capital allows actors needing water to not only invest in infrastructure, but to buy it from others with a water surplus (water rich communes, water cooperatives, or private businesses such as the hydropower company) (Reynard 2000b). However, there are as many as 11 separate drinking water distribution systems, more or less coordinated into 3 intercommunal networks, and this separation prevents water sharing between upstream and downstream communes (Bonriposi 2013).

4.1.4.2. Collaborative capacity. Most of the numerous collaborative efforts, including joint construction and use of pipelines and agreements about water sharing (e.g. ceding water rights or exchanging them for the right to build a pipeline on the territory of the other commune), have been started on an ad hoc basis. These ad hoc agreements established high levels of flexibility and bilateral connectivity. However, few collaborative efforts involve all communes in the region, both those upstream and downstream (Schneider and Homewood 2013). For example, there is no association linking all communes and major water users of the region (Reynard 2000b; 2001; Bréthaut 2012). Moreover, there has been limited success in defining joint visions for future proactive responses to water problems (Schneider and Homewood 2013).

4.1.4.3. Institutions and entitlements. The assessment of adaptive capacity based on the current entitlements provides ambiguous results (Schneider and Homewood 2013). The existing institutional structure provides considerable scope of action in that it has allowed people to flexibly negotiate case by case agreements. A prominent example is the renegotiation of ancient water rights to develop the hydropower concession (Bréthaut 2012). However, the institutional structure itself is rather inflexible because of its strong historicity, predefined uses, and legal obscurity (there are hundreds of water rights that are legally valid to this day, but no complete overview). This is especially true of ancient water rights (including non-formalized customary law) that have endured for centuries (in particular a sentence dividing the water between communities dating back to 1490) (Reynard 2000b; Ammann 2011). While these water rights reflect the needs of the people in the 15th century, they do not necessarily reflect current needs related to tourism and hydropower production.

4.1.4.4. Resource efficiency. Efforts to mitigate water shortage problems remained rare, e.g. managing water demand by separating the drinking and irrigation water infrastructure, promoting more efficient irrigation such as drip irrigation, or eliminating water loss by repairing leaks. Only in times of acute water crises are people called to temporarily save water, for example, by prohibiting agricultural and garden irrigation or car washing. Moreover, regional planning (e.g. for the construction of tourism infrastructure) often takes place without taking into account the related increase in regional water demand. These developments, however, create water use structures and water needs that may in the future limit the scope of action (Schneider and Homewood 2013).

4.1.4.5. Social learning. Learning processes are shaped by the actors' continuous involvement in dealing with water shortage on the local scale (e.g. learning by doing – single loop learning). As a result, their responses tend to favor local and step by step solutions based on infrastructure and ad hoc agreements. This has enabled the actors to solve many shortage problems. However, as mentioned above, this infrastructure network is also fragmented due to its polycentric and step by step evolution (Schneider and Rist 2013b). There are very limited provisions for learning on a regional scale, which also fosters reflections and transformations of the underlying norms of interaction (e.g. holistic regional water visions – double loop learning), and addresses the conditions that structure these norms (e.g. the water right situation – triple loop learning) (Schneider and Homewood, 2013).

4.2. Sustainability assessment of the future

By comparing the sustainability wheels of the four different future visions (Figure 4), it is apparent that sustainability will decline with Vision 1, while it will improve with Visions 2, 3, and RegiEau. The reasons for these results, however, are complex and come from different combinations of regional development, infrastructure projects, and institutional reforms.

All four future visions make the same assumptions regarding the evolution of natural water availability due to climate change scenarios. According to these scenarios, the overall natural water availability and the seasonal distribution will only change slightly before 2050–2060; however, during this time it is expected that summers will be drier and hotter (Schär *et al.* 2004) and drought periods more frequent (Fatichi *et al.* 2013; Fuhrer, Smith, and Gobiet, forthcoming). Runoff in the rivers that are recharged by the glacier is expected to increase by about 30% during the summer months due to increased glacier melting (Huss, Voinesco, and Hoelzle 2013). This means that regional development activities that are directly dependent on hydrometeorological conditions (e.g. agriculture in areas that cannot be irrigated) will generally face more difficulties, whereas activities such as hydropower production, which currently have the rights to use the water of the biggest glacier recharged catchment, will benefit.

However, as mentioned above, the sustainability of the water governance system as a whole can evolve in quite different directions depending on the socioeconomic and institutional developments. For example, the indicator *surface water quantity* does not only depend on the natural water availability, but also on the withdrawals of water, and regulations such as the Swiss Water Protection Act, which determines residual flows (Swiss Confederation 2013). In 2037, when the hydropower concession ends, the residual flows will have to be restored by the hydropower companies. Compared to the current situation, this will improve the environmental situation in the affected streams and brooks.

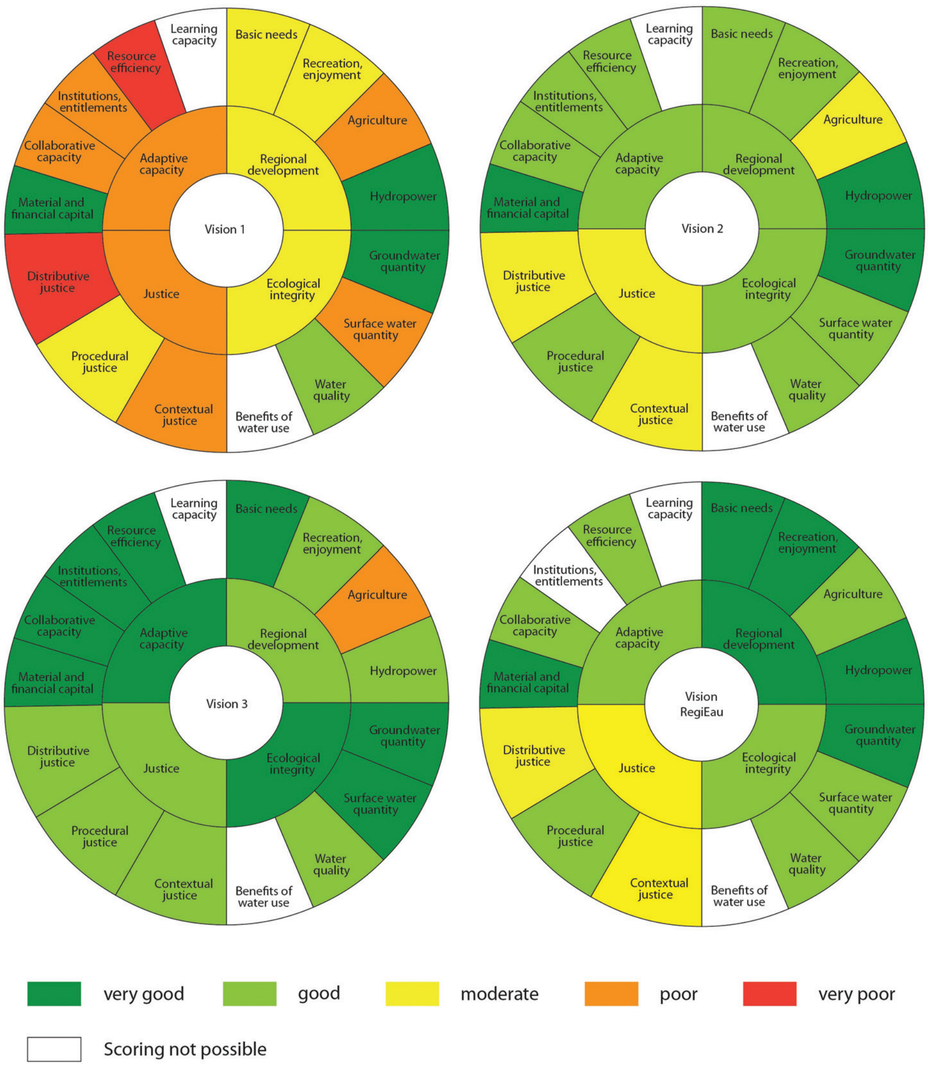

Figure 4. The sustainability wheels for four different future visions for 2050. See online color version for full interpretation.

This is true even if new reservoirs and hydropower plants might be constructed, as they will have to consider the residual flow standards as well. Thus, independent of the exact amount of residual flow envisioned (50%, 100%, and 200% of the actual law in effect), the indicator *surface water quantity* is set to improve. This is also the case for Vision 1 (only 50% of the actual law in effect) because today minimum flow is not implemented at all. In Vision 2 and RegiEau, the residual flow must conform to the actual law and, therefore, the indicator is rated as good; in Vision 3 it is set as very good, as the residual flow is voluntarily doubled and, as a consequence, the ecosystem will benefit even more.

In the following, we outline the basic considerations that guided the sustainability assessment of the four visions (see Table 1).

In Vision 1, sustainability is determined to decrease as measured by most indicators. This is mainly the consequence of a considerable increase in the overall water demand due to intense population growth and unrestrained economic development (e.g. mass tourism) (Bonriposi 2013) combined with unsatisfactory steps towards institutional reforms, collaboration, and water demand management practices (Schneider and Homewood 2013). We argue that under future conditions of increased pressure on the resource as foreseen in this vision, institutional reforms might be necessary to maintain an even similar amount of adaptive capacity, justice, and water security.[1] Otherwise, current temporal and local water shortages (occurring in some communes in summertime, in the tourist resort in wintertime) will be exacerbated, and communes that can now afford to sell water will eventually be unable to sell their water to others in need.

In this vision, only the infrastructure capacity that includes hydropower production is expected to increase due to the forceful supply management philosophy and the extensive development of new water infrastructure. However, the potential of the improved infrastructure system cannot be put into effect and translated to the other domains if there are no institutional reforms. For example, without solving the problems related to unequal water rights distribution, the infrastructure project cannot fundamentally improve the situation for those communes that currently suffer the greatest water insecurities due to lack of water rights.

In Vision 2, sustainability of most indicators is predicted to improve to good status. This is despite the fact that the overall water demand is assumed to increase due to the increasing importance of agricultural production and the related use of irrigation water. However, this vision does not only foresee infrastructure developments (diverse water storage and diverting projects), but is also guided by an optimization philosophy where all water uses are optimized and important institutional reforms, such as centralized water management and water rights reforms, are implemented. Thus, the assessment determined that these combined management efforts are able to deal with the increased water demands in most cases and even contribute to higher justice. However, the assumed intensification of agriculture, the most significant water user in the region (Bonriposi 2013), will also make the sector more vulnerable to drought conditions, which are considered to become more frequent in the future (see hydrological modeling). Moreover, the justice situation is still set as only moderate, as decisions must be made unanimously and, therefore, water rich communes can hinder negotiation processes towards the wellbeing of all.

In Vision 3, sustainability is determined to increase even more to the good and very good ranks. This is the result of decreasing water demands due to adapted economic activities (e.g. no artificial snow production), reduced population, and extensive water saving practices, combined with an optimized management system that is oriented towards the wellbeing of all people of the region. This is particularly beneficial for the justice scores. However, the satisfaction of the water demand for agriculture will clearly decrease. It is the requirement to leave greater residual water flow in rivers that will decrease the water availability for irrigation, especially in the latter part of summer when river flows are naturally quite low and the water needs for irrigation and evapotranspiration are higher.

In the Vision of RegiEau, sustainability is also determined to increase and ranges between that of Vision 2 and 3. Although the Vision of RegiEau resembles Vision 2 in many aspects of regional development, its sustainability assessment resulted in higher scores, mainly because it incorporates more supply and demand management practices (e.g. dispersed storage of rain water), and it is oriented towards the wellbeing of all people of the region (as is Vision 3). However, in contrast to Vision 3, the participants could not find agreement on the issue of water rights reform. Consequently, several indicators are set slightly lower than in Vision 3 (e.g. *collaborative capacity*, *distributive*, *and contextual justice*) and the indicator *institutions and entitlement* could not be rated at all.

5. Conclusions

We have presented and tested a conceptual and methodological approach for assessing the sustainability of water governance systems in an interdisciplinary way. The application of the sustainability wheel used an approach that combined transparent identification of sustainability principles, their regional contextualization through sub-principles (indicators), and the scoring of these indicators through deliberative dialogue within an interdisciplinary team of researchers taking into account their joint research results.

We applied the sustainability wheel to the case study area Crans-Montana-Sierre region, demonstrating the following advantages:

(1) It allowed very different sources of knowledge (research from natural and social sciences, qualitative and quantitative knowledge, empirical, and interpretative approaches) to be combined and brought to fruition. Consequently, it facilitated in-depth interactions, knowledge exchange, and learning among the interdisciplinary team of researchers.
(2) It allowed the consideration of complex relationships between issues of resource availability, water use, and management. In doing so, it was evident that certain measures, such as a strong increase in residual flow, might improve the indicator of surface water quantity; however, the needs of agriculture would be compromised as a result, thus affecting the indicator of agriculture. Furthermore, it could clearly be shown that sustainable water futures can be reached (and also impeded) through different means. For example, Vision 3 envisioned reduced water demands, while Vision RegiEau foresees extensive infrastructure developments. However, it also became clear that technical solutions alone will not solve the existing access and distribution. These solutions need to be embedded in fundamental institutional reforms.
(3) It permitted the information from disciplinary works to be structured in a meaningful way and allowed their implications to be elucidated from a comprehensive understanding of sustainability. It allowed us to easily discern which sustainability dimensions are most critical, both for today and for the different future visions, facilitating communication with stakeholders considerably. They could easily see that the water governance system can respond quite well to society's goals of regional development and also that the situation regarding water justice is critical. Moreover, they were able to see that sustainable water futures are possible as well, although this highly depends on the social, economic, technical, and institutional reforms they are willing to take. Discussions about the reasons for certain scoring made stakeholders aware of possible tradeoffs between the indicators (e.g. strongly increased residual flows improve the indicator of surface water quantity but downgraded the indicator of agriculture). The sustainability wheel can thus be considered an excellent communication instrument.

Some of the researchers involved in this study would have preferred a more quantitative, modeling based final assessment and the development of simple, quantitative indicators that could be easily replicated. However, they also recognized that a quantitative assessment could not have provided a more accurate overall picture of the water governance system in place, given its high complexity and uncertainty. Yet, the following challenges should be carefully considered in future applications of the sustainability wheel:

(1) In our study, we developed the sustainability principles in the second half of the project. As a consequence, we were not able to generate all of the knowledge required for all indicators, e.g. knowledge regarding the ecological effects of different water uses. For future applications, the sustainability principles and their contextualization should be conducted in the very beginning of the research project, together with the research framework concerning the production of empirical knowledge.
(2) The heterogeneity of the principles and indicators, and the complexity of the interrelationships, made a consistent assessment very demanding. For example, better collaborations through novel regional water governance organizations can have an effect on different indicators such as collaborative capacity, learning capacity, and procedural justice, and also on water security as a whole. Therefore, these possible relationships should be clearly outlined in the beginning of the scoring process and a facilitator should be assigned to make sure that they are thoroughly taken into account.
(3) The sustainability wheels, with their ample color scoring systems, are very strong messengers, and they suggest priorities of action. Therefore, it is of crucial importance to carefully consider in which cases an indicator is assessed as good, or bad, keeping the overall picture and the related message in mind. That is, which dimensions are set red, which ones are set green? For example, what is a moderate level of justice compared to a moderate level of ecological integrity?
(4) To jointly assess the multitude of interdisciplinary knowledge, the participating researchers need a high level of communication skills, willingness to listen to the arguments of other researchers, and basic understanding of the topics of other researchers. In our study, this was achieved through an intense collaboration and learning process that began at the start of the research project. Thus, if a deliberative sustainability assessment is planned, emphasis should be placed on social learning processes during and in preparation for the event.
(5) Assessment of future sustainability situations is highly dependent on the identified visions. In our case, the researchers who were well acquainted with the situation tended to internalize the political and social constraints, and were tempted to reduce their propositions and ideas for the future to what seemed reasonable and feasible without touching existing power relationships (problem of self-censorship). Despite the fact that more ambitious and critical visions might not be able to be currently implemented, they can still contribute to critically thinking about radically alternative futures and profound reforms and change.

By considering the above mentioned points, the presented methodological approach can be applied to other case study regions. While the general principles will be suitable for most regional situations, the specific indicators should be adapted according to specific local characteristics. This is particularly true for the indicators of regional development (e.g. hydropower, which might not be relevant, may need to be replaced by industrial water use). We further think that the approach presented here can also successfully be applied by smaller research teams, teams of professional experts, and stakeholder groups. In all cases, however, it is important that the process is accompanied by a facilitator that oversees sound planning, equal involvement of all participants and knowledge bases, and coherency of the rating process and the developed storylines.

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Note

1 By using the term water security, we refer to a broad definition of the term that includes access to adequate quantities of acceptable quality of water for both humans and the environment (GWP 2000).

References

Adger, W.N., N.W. Arnell, and E.L. Tompkins. 2005. "Successful Adaptation to Climate Change Across Scales." *Global Environmental Change* 15 (2): 77–86.

Ammann, H.-R. 2011. "Autour De l'eau De La Raspille (XVe-XXe Siècles)." In *Les Bisses: économie, société, patrimoine*, edited by S. Nahrath, J.-H. Papilloud, and E. Reynard, 253–269. Sion: Société d'Histoire du Valais Romand.

ASCE (American Society of Civil Engineers) and UNESCO (United Nations Organization for Education, Science and Culture). 1998. *Sustainability Criteria for Water Resource Systems*. Report prepared by the Task Committee on Sustainability Criteria, W.R.P.a.M.D. Reston: Asce and Working Group Unesco/Ihp Iv Project M-4.3.

Babel, M., V. Pandey, A. Rivas, and S. Wahid. 2011. "Indicator-Based Approach for Assessing the Vulnerability of Freshwater Resources in the Bagmati River Basin, Nepal." *Environmental Management* 48 (5): 1044–1059. doi: 10.1007/s00267-011-9744-y.

Bonriposi, M. 2013. "Les usages de l'eau dans la Région de Crans-Montana-Sierre: description, quantification et previsions." PhD diss., University of Lausanne.

Bréthaut, C. 2012. Analyse Comparée De Régimes Institutionnels De Gestion Des Réseaux Urbains De l'eau en Stations Touristiques De Montangen: Les Cas de Crans-Montana (Suisse) et de Morzine-Avoriaz." PhD diss., Sion: University of Lausanne.

Buff, C. 2012. *Bedeutung(en) von Wasser im Weinbau in der Region Crans-Montana-Sierre*. BSc diss., University of Bern.

CH2011. 2011. "Les scénarios du changement climatique en Suisse CH2011 [Document numérique en ligne]." Disponible sur. Accessed May 8 2012. http://www.ch2011.ch.

Clivaz, C., and E. Reynard. 2008. "Crans-Montana: Water Resources Management in an Alpine Tourist Resort." In *Mountains: Sources of Water, Sources of Knowledge,* edited by E. Wiegandt, 103–119. Berlin: Springer.

Crestin, G. 2001. "Vulnérabilité du Milieu Karstique de la Région De Montana (Valais, Suisse)." Neuchâtel: M.Sc. thesis, Centre d'Hydrogéologie de l'Université de Neuchâtel.

Fatichi, S., S. Rimkus, P. Burlando, R. Bordoy, and P. Molnar. 2013. "Elevational Dependence of Climate Change Impacts on Water Resources in an Alpine Catchment." *Hydrology and Earth System Sciences Discussions* 10 (3): 3743–3794.

Finger, D., A. Hugentobler, M. Huss, A. Voinesco, H. Wernli, D. Fischer, E. Weber, P.-Y. Jeannin, M. Kauzlaric, and A. Wirz. 2013. "Identification of Glacial Meltwater Runoff in a Karstic Environment and Its Implication for Present and Future Water Availability." *Hydrology and Earth System Sciences* 17 (8): 3261–3277.

Folke, C., T. Hahn, P. Olsson, and J. Norberg. 2005. "Adaptive Governance of Social-Ecological Systems." *Annual Review of Environment and Resources* 30: 441–473.

Fraser, N. 2009. *Scales of Justice: Re-Imagining Political Space in a Globalizing World*. New York: Columbia University Press.

Fuhrer, J., P. Smith, and A. Gobiet Forthcoming. "Implications of Climate Change Scenarios for Agriculture in Alpine Regions – a Case Study in the Swiss Rhone Catchment." *Science of the Total Environment*. http://dx.doi.org/10.1016/j.scitotenv.2013.06.038.

Gibson, R.B. 2006. "Sustainability Assessment: Basic Components of a Practical Approach." *Impact Assessment and Project Appraisal* 24 (3): 170–182.
Gleick, P.H. 1998. "Water in Crisis: Paths to Sustainable Water Use." *Ecological Applications* 8 (3): 571–579. doi: 10.1890/1051-0761(1998)008[0571:wicpts]2.0.co;2.
Gupta, J., C. Termeer, J. Klostermann, S. Meijerink, M. Van Den Brink, P. Jong, S. Nooteboom, and E. Bergsma. 2010. "The Adaptive Capacity Wheel: A Method to Assess the Inherent Characteristics of Institutions to Enable the Adaptive Capacity of Society." *Environmental Science & Policy* 13 (6): 459–471.doi: 10.1016/j.envsci.2010.05.006.
GWP (Global Water Partnership). 2000. *Towards Water Security: A Framework for Action*. Stockholm
Hartmuth, G., K.: GWP Huber, and D. Rink. 2008. "Operationalization and Contextualization of Sustainability at the Local Level." *Sustainable Development* 16 (4): 261–270. doi: 10.1002/sd.377.
Hill, M. 2013. *Climate Change and Water Governance: Adaptive Capacity in Chile and Switzerland*. Dordrecht: Springer.
Huss, M., A. Voinesco, and M. Hoelzle. 2013. "Implications of Climate Change on Glacier de la Plaine Morte." *Geographica Helvetica* 68: 227–237.
Ioris, A.a.R., C. Hunter, and S. Walker. 2008. "The Development and Application of Water Management Sustainability Indicators in Brazil and Scotland." *Journal of Environmental Management* 88 (4): 1190–1201. doi: 10.1016/j.jenvman.2007.06.007.
Kobel, E. 2014. *Zum Verhältnis von Wandel, Zukunftsempfinden und Bewässerung in der Landwirtschaft*. Schweiz: MSc diss., University of Bern.
Kondratyev, S., T. Gronskaya, N. Ignatieva, I. Blinova, I. Telesh, and L. Yefremova. 2002. "Assessment of Present State of Water Resources of Lake Ladoga and Its Drainage Basin Using Sustainable Development Indicators." *Ecological Indicators* 2 (1): 79–92.
Lachavanne, B., and R. Juge. 2009 "LEMANO. Pour une gestion durable de l'eau." *Lémaniques* (72): 1–16.
La Lienne SA. 2012. *Rapport de gestion 2011/2012*. Sion: La Lienne SA http://www.esr.ch/media/esr/document/0/ELSA%20Rapport%20de%20Gestion%202011-2012.pdf.
Larson, K.L., A. Wiek, and L. Withycombe Keeler. 2013. "A Comprehensive Sustainability Appraisal of Water Governance in Phoenix, AZ." *Journal of Environmental Management* 116: 58–71.
McDermott, M., S. Mahanty, and K. Schreckenberg. 2013. "Examining Equity: A Multidimensional Framework for Assessing Equity in Payments for Ecosystem Services." *Environmental Science and Policy* 33: 416–427. doi: http://dx.doi.org/10.1016/j.envsci.2012.10.006.
Olsson, P., L.H. Gunderson, S.R. Carpenter, P. Ryan, L. Lebel, C. Folke, and C.S. Holling. 2006. "Shooting the Rapids: Navigating Transitions to Adaptive Governance of Social-Ecological Systems." *Ecology and Society* 11 (1): 18. http://www.ecologyandsociety.org/vol11/iss1/art18/.
Pahl-Wostl, C. 2006. "The Importance of Social Learning in Restoring the Multifunctionality of Rivers and Floodplains." *Ecology and Society* 11 (1)10. http://www.ecologyandsociety.org/vol11/iss1/art10/.
Pahl-Wostl, C. 2009. "A Conceptual Framework for Analysing Adaptive Capacity and Multi-level Learning Processes in Resource Governance Regimes." *Global Environmental Change* 19 (3): 354–365.
Pahl-Wostl, C., M. Craps, A. Dewulf, E. Mostert, D. Tabara, and T. Taillieu. 2007. "Social Learning and Water Resources Management." *Ecology and Society* 12 (2): 5. http://www.ecologyandsociety.org/vol12/iss2/art5/
Quaglia, L. 1988. *Le Mont de lens*. Lens: Administration Communale de Lens.
Reed, P.M., and J. Kasprzyk. 2009. "Water Resources Management: The Myth, the Ticked, and the Future." *Journal of Water Resources Planning and Management* 135 (6): 411–413.
Reynard, E. 2000a. "Cadre institutionnel et gestion des ressources en eau dans les Alpes: deux etudes de cas dans des stations touristiques valaisannes." *Swiss Political Science Review* 6 (1): 53–85.
Reynard, E. 2000b. "Gestion patrimoniale et intégrée des ressources en eau dans les stations touristiques de montagne: Les cas de Crans-Montana-Aminona et Nendaz (Valais)." PhD diss., University of Lausanne.
Reynard, E. 2001. "Aménagement du territoire et gestion de l'eau dans les stations touristiques alpines. Le cas de Crans-Montana-Aminona (Valais, Suisse)." *Revue de géographie alpine* 89 (3): 7–19.

Reynard, E., and M. Bonriposi. 2012. “Water Use Management in Dry Mountains of Switzerland. The Case of Crans-Montana-Sierre Area.” In *The Impact of Urbanisation, Industrial, Agricultural and Forest Technologies on the Natural Environment*, edited by M. Neményi and H. Balint, 281−301. Sopron: Nyugat-magyarorszagi Egyetem.
Reynard, E., M. Bonriposi, O. Graefe, C. Homewood, M. Huss, M. Kauzlaric, H. Liniger, E. Rey, S. Rist, B. Schädler, F. Schneider, and R. Weingartner. 2014. “Interdisciplinary Assessment of Complex Regional Water Systems and Their Future Evolution: How Socio-Economic Drivers can Matter More than Climate.” *WIREs Water* 1 (4): 413−426. doi: 10.1002/wat2.1032.
Rixen, C., V. Stoeckli, and W. Ammann. 2003. “Does Artificial Snow Production Affect Soil and Vegetation of Ski Pistes? A Review.” *Perspectives in Plant Ecology, Evolution and Systematics* 5 (4): 219−230.
Schär, C., P.L. Vidale, D. Lüthi, C. Frei, C. Häberli, M. Liniger, and C. Appenzeller. 2004. “The Role of Increasing Temperature Variability in European Summer Heat Waves.” *Nature* 427: 332−336.
Schlosberg, D. 2007. *Defining Environmental Justice: Theories, Movements, and Nature*. New York: Oxford University Press.
Schneider, F., T. Buser, and O. Graefe. Forthcoming. “Scales of Justice in Water Governance: Hydropower Controversies in Switzerland.” *Water Policy*.
Schneider, F., and C. Homewood. 2013. “Exploring Water Governance Arrangements in the Swiss Alps from the Perspective of Adaptive Capacity.” *Mountain Research and Development* 33 (3): 225−233.
Schneider, F., and S. Rist. 2013a. “Envisioning Sustainable Water Futures in a Transdisciplinary Learning Process: Combining Normative, Explorative, and Participatory Scenario Approaches.” *Sustainability science* 9: 1−19. doi: 10.1007/s11625-013-0232-6.
Schneider, F., and S. Rist. 2013b. “Transitions to Sustainable Water Governance from a Social Learning Perspective.” Proceedings of the Fourth International Conference on Sustainability Transitions, Zurich, June 20.
Schürch, M., and F. Vuataz. 2000. “Groundwater Components in the Alluvial Aquifer of the Alpine Rhone River Valley, Bois de Finges area, Wallis Canton, Switzerland.” *Hydrogeology Journal* 8 (5): 549−563.
Sullivan, C., and J. Meigh. 2007. “Integration of the Biophysical and Social Sciences Using an Indicator Approach: Addressing Water Problems at Different Scales.” *Water Resources Management* 21 (1): 111−128. doi: 10.1007/s11269-006-9044-0.
Swiss Confederation. 2013. *Federal Act on the Protection of Waters (Waters Protection Act, WPA)*. No. 814.20. Bern: Swiss Confederation.
Tompkins, E.L., and W. Adger. 2004. “Does Adaptive Management of Natural Resources Enhance Resilience to Climate Change?” *Ecology and Society* 9 (2): 10. http://www.ecologyandsociety.org/vol9/iss2/art10/
Valenzuela Montes, L.M., and A. Matarán Ruiz. 2008. “Environmental Indicators to Evaluate Spatial and Water Planning in the Coast of Granada (Spain).” *Land Use Policy* 25 (1): 95−105. doi: 10.1016/j.landusepol.2007.03.002.
WCED (World Commission on Environment and Development). 1987. *Our Common Future (“The Brundtland Report”)*. Oxford: Oxford University Press.
Weingartner, R., D. Herweg, H. Liniger, S. Rist, B. Schädler, F. Schneider, O. Graefe, M. Hoelzle, and E. Reynard. 2010. “Water Scarcity in Inner-Alpine Regions. Options for Sustainable Water Use in the Crans-Montana-Sierre Region (Valais).” *MRI Newsletter No.* 5. December 2010, 13−15.
Weingartner, R., and M. Spreafico. 2010. *Hydrologischer Atlas der Schweiz*. Bern: Bundesamt für Wasser und Geologie.
White, D.D. 2013. “Framing Water Sustainability in an Environmental Decision Support System.” *Society and Natural Resources* 26 (11): 1−9 DOI:10.1080/08941920.2013.788401.
Wiek, A., and K. Larson. 2012. “Water, People, and Sustainability—A Systems Framework for Analyzing and Assessing Water Governance Regimes.” *Water Resources Management* 26 (11): 3153−3171. doi: 10.1007/s11269-012-0065-6.